NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report No. 32-763

A Pressure Telemeter for Wind-Tunnel Free-Flight Pressure Measurement

Royal G. Harrison, Jr.

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

February 1, 1966

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report No. 32-763

A Pressure Telemeter for Wind-Tunnel Free-Flight Pressure Measurement

Royal G. Harrison, Jr.

C. M. Berdahl

C. M. Berdahl, Manager
Instrumentation Section

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

February 1, 1966

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

CONTENTS

FIGURES

N66-16748

ABSTRACT

This Report summarizes the work on a pressure telemeter—the instrument, itself, and the applicable telemetry technique—developed for use in studying interference-free pressures on models launched into free flight in a hypersonic, continuous-flow wind tunnel. Design characteristics, performance, and operational procedures, as well as problems that were delineated during the development phase, are described. The pressure measurements obtained during the experiments were of base pressures on 10- and 15-deg half-angle cones. There was good correlation between theoretical predictions and experimental data, and findings confirm that the pressure telemeter is operational and produces valid data.

author

INTRODUCTION

Pressure telemeters have been developed at the Jet Propulsion Laboratory Aerodynamics Facility to study interference-free pressure data on models that are projected into free flight by a pneumatic launch mechanism. A wind tunnel test program has been conducted (Ref. 1), making pressure measurements of base pressures on 10- and 15-deg half-angle cones.

The instruments (Fig. 1) that were developed for, and used in, these tests were designed to function, unaffected,

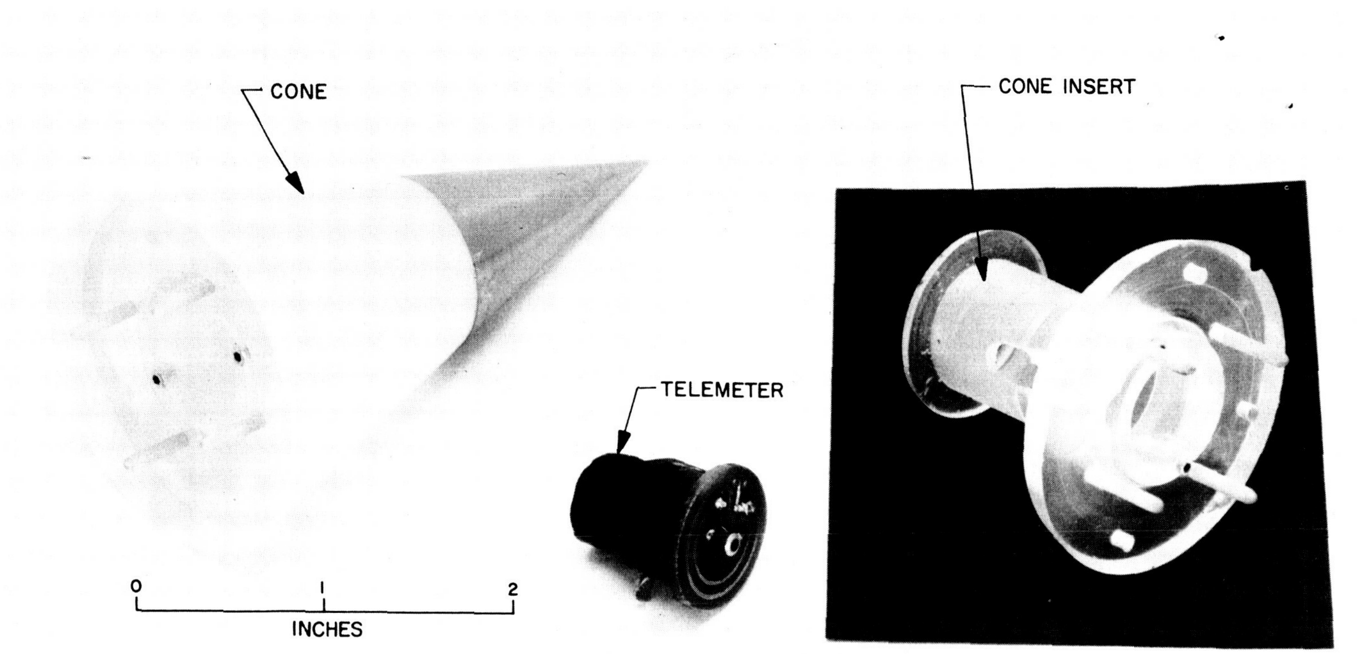

Fig. 1. Free-flight telemeter model

over the wide ranges of pressures, temperatures, and accelerations encountered during launch and free flight. Protection of the unit while it was on the launch gun was provided by a heat shield (Fig. 2) and a cooling gas, maintaining a temperature range such that the heat would not distort the model and that the pressure telemeter would not exceed its operating temperature range.

The heat shield also provided a nose support for the model and protected it from buffeting when the wind tunnel was started. Usually, during the time (approximately 15 min) that was required to bring the wind tunnel up to operating pressure and temperature, the telemeter had stabilized and was ready for free-flight measurement. Then the model nose support was withdrawn, reference pressure measured, heat shield raised, and the plastic model—which had a steel nose to prevent melting during the flight—was launched into free flight.

An attempt was made to catch the model at the end of the flight, but this was not always successful. When it was not caught, the model itself was totally destroyed; however, because of the protection of the lucite insert (Fig. 1), the telemeter was generally recoverable.

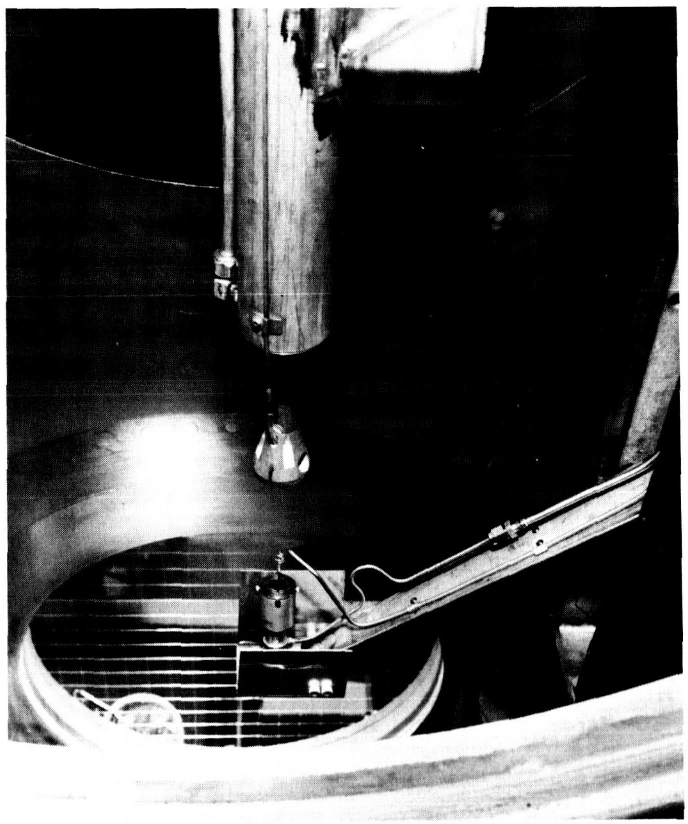

Fig. 2. Launch gun and heat shield

II. TELEMETER PERFORMANCE

The pressure-telemeter full-scale pressure measurement capabilities are limited by the bandwidth capabilities of the receiver used—in this case, the bandwidth was 200 kc. Three sensitivities were produced at 1-mm Hg: 20, 40, and 80 kc.

The pressure telemeters are insensitive to the accelerations encountered during wind tunnel operations. At 25 *g* there proved to be no measurable effects with the instrumentation used for data recording. This was determined by firing a model with a telemeter into a padded box with the pressure port sealed, repeating the exercise with several models of various sensitivities, and computing the acceleration each time.

The oscillator stability was found to be 0.001% of the oscillator frequency over a period of 30 min. For a period of 1 min, the stability was found to be 0.5% of 200 kc. This was determined with the pressure telemeter in a bell jar at a constant pressure to eliminate atmospheric disturbances, and monitoring the oscillator frequency with a Hewlett Packard, Model 524B, electronic counter. For periods of time comparable to free-flight periods, no deviations could be recorded.

The rise-time capabilities of the pressure telemeters are 0.5 msec, or better, without tubing or a bypass capacitor on the tuner's discriminator output. The diaphragm of the pressure sensor vibrates at its natural frequency, with a time constant of 2 msec, when a sharp pressure pulse is applied. The rise times were determined by using a small shock tube to generate the pressure pulse.

The pressure telemeter thermal stability was thoroughly investigated and found to be quite good for the stable test times required. A temperature increase of 100°F, with an ambient pressure of 14 psi, produced a 2.7% increase in the oscillator frequency. The time interval between the temperature increase and the start of the oscillator's shift in frequency was 3 min. The telemeter could be exposed to 800°F for at least 10 sec before any oscillator shift began. These thermal stability measurements were made in an electric oven that was well regulated. An investigation of the effects of thermal shock was performed in the same manner; there were no effects noted. The 100°F temperature rise also produced a 0.1% change in the full-scale calibration of the pressure telemeter. There are little, or no, changes in the performance of the telemeter over a temperature range of 30 to 200°F.

The pressure telemeter, which is a differential transducer, can be subjected to an over-pressure of 50 psi without damage or change in performance. The reference pressure is obtained by a very slow leak into the large volume of the reference side of the sensor. This leak rate can be adjusted easily to provide stable measurement times for as long as 5 sec at atmospheric pressure; as the ambient pressure decreases, this time can be increased.

The diaphragm natural frequencies are from 20 to 27.5 kc, depending on the assigned diaphragm thickness and tension.

III. PRESSURE TELEMETER DESIGN AND CONSTRUCTION

The primary performance requirement of the pressure telemeter is a stable, consistent operation. Secondary requirements are simplicity of assembly and of operation. To achieve these aims special techniques and materials were avoided as much as possible, the number of components was held to a minimum, and the circuit which was used was known to be inherently stable. The Colpitts oscillator (Fig. 3) was used because of its insensitivity to variations of the circuit components other than the tank circuit.

The telemeter, ready for assembly, consists of four major components, which are shown in Fig. 4: a printed circuit inductor, a pressure-sensitive capacitor, a battery, and all other circuit components in a microminiature package of pellet type construction[1] (Fig. 4).

[1]Manufactured by Electrolab-Electronics Corp., EXI Division, Los Angeles, California.

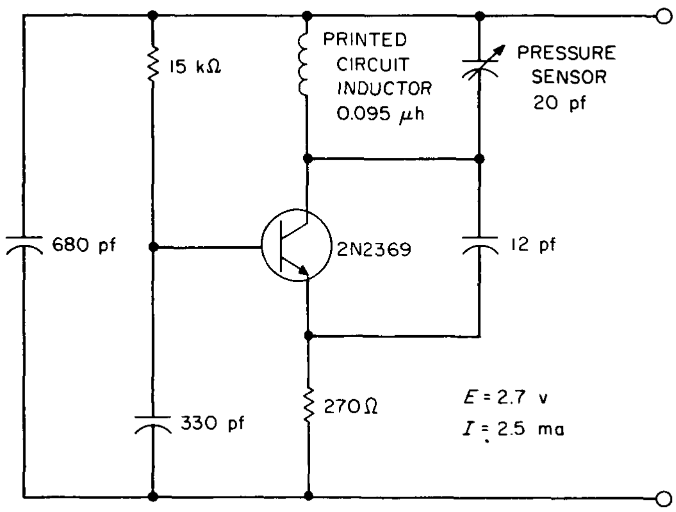

Fig. 3. Schematic diagram of telemeter oscillator

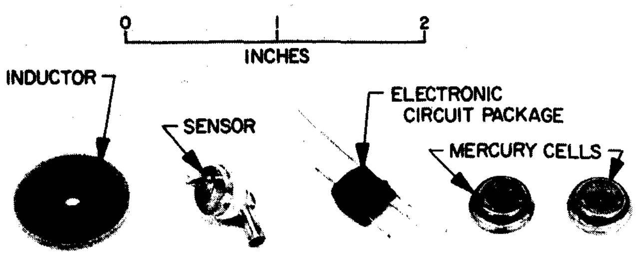

Fig. 4. Telemeter components

The characteristics and technique of fabrication of the pressure sensor were determined empirically, for the most part, because of the uncertainties of mathematically determining the characteristics of very thin metal diaphragms under tension (Fig. 5). Before assembly of the sensor, the diaphragm was examined for proper tension by pumping down the reference side and measuring the focal length of the concave surface. For example, a focal length of 1.3 in. at a pressure of 14 psi would, at final assembly of the pressure telemeter, provide a sensitivity of 20 kc ±10% for a pressure difference of 1 mm Hg. Two diaphragm thicknesses were used, with variations in tension to provide a selection of sensitivities.

After assembly of the sensor, it was checked for proper capacitance on a Q meter and, then, attached to the inductor, where the tank circuit was checked for proper resonant frequency with a grid-dip oscillator. The microminiature circuit was then attached, and the pressure telemeter checked for proper operation before potting. The resonant frequency of the circuit changes very little after potting. The mercury cells which are attached with a hard sealing wax, can be changed in a matter of minutes, if necessary. The extreme toughness of the potting material has enabled the telemeter to survive high temperatures and high-velocity impact.

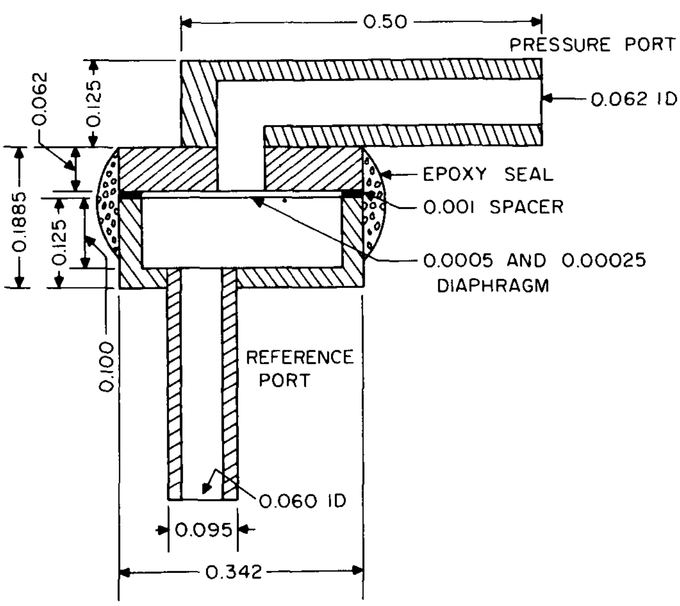

Fig. 5. Pressure sensor

The pressure telemeter is 0.80-in. long, 0.80-in. diam at the inductor end, and 0.50-in. diam at the battery end (Fig. 6); the total weight of the instrument is 1/3 oz. The useful battery life averages about 20 hr, which duration is ample for calibration and wind tunnel operations. Almost all battery failures occur during calibration. It has been noted that a change in temperature of 100°F will produce a change in battery voltage of about 1%.

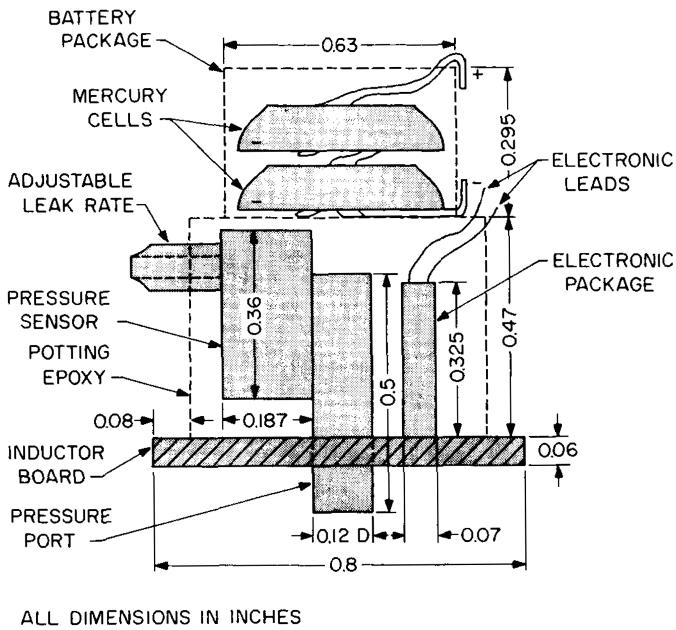

Fig. 6. Pressure telemeter components layout

IV. CALIBRATION

The process of calibrating a pressure telemeter begins with placing it in a bell jar (Fig. 7), which is pumped down to simulate, approximately, the wind tunnel static pressure. A strain-gauge transducer and readout system with a scale factor of 5μ per division, is zeroed at this condition. The FM tuner is adjusted to center frequency, and the output of the discriminator is displayed on the Y axis of an oscilloscope. A small volume of gas is admitted to the bell jar, causing a sharp pressure step. The calibration-system rise time is about 10 msec.

The sweep of the oscilloscope, which is triggered at the same time the gas is admitted, records the frequency shift of the pressure telemeter. The strain-gauge pressure transducer reading is then recorded to provide a pressure measurement corresponding to the voltage measurement on the oscilloscope (Fig. 8). To record a pressure decrease, a large volume at vacuum is opened to the bell jar, causing a sharp pressure decrease.

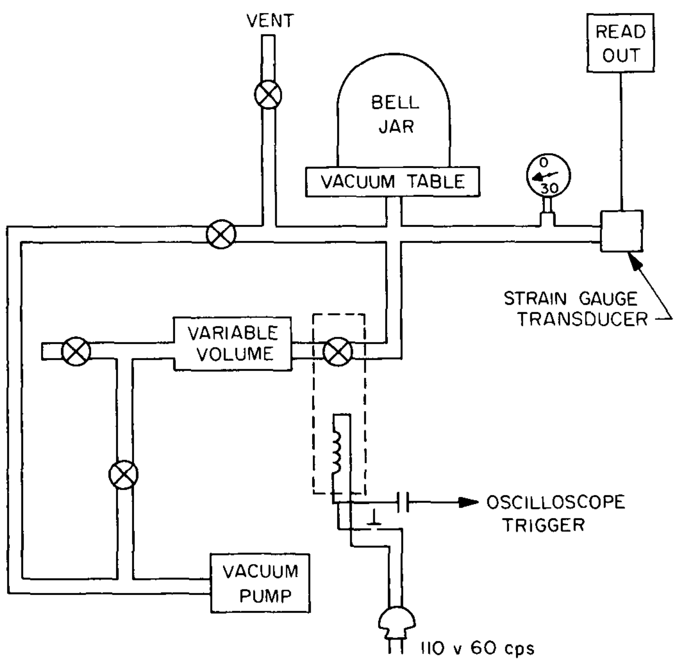

Fig. 7. Calibration system

The telemeters have been found to be linear in the area of interest; no change in the calibration slope occurs in going from a pressure increase to a pressure decrease (Fig. 9). The leak rate of the sensor is adjusted at the beginning of the calibration. After calibration, the pressure telemeter is ready either for immediate use in the wind tunnel or for storage for a reasonable time without a change in calibration.

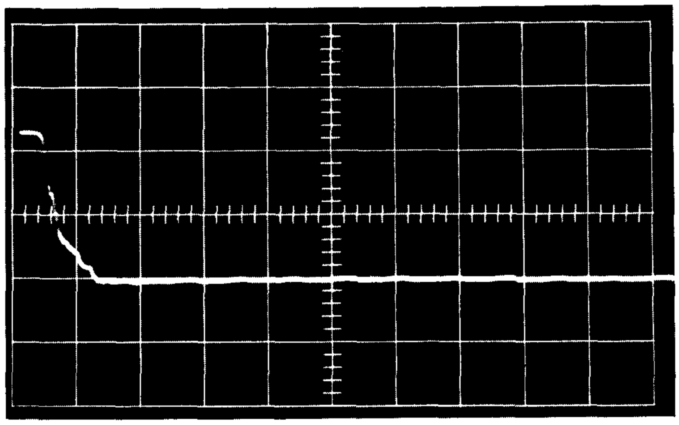

Fig. 8. Typical calibration pulse; $\Delta P = 200\ \mu$ Hg; $X = 20$ msec/cm; $Y = 50$ mv/cm

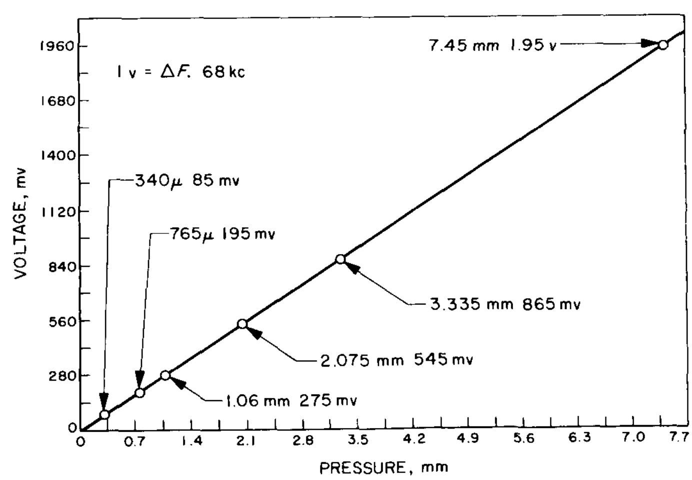

Fig. 9. Telemeter calibration curve

V. RECORDING INSTRUMENTATION

A standard McIntosh FM tuner (Model MR71), realigned to tune through 98 to 118Mc,was used to receive the pressure telemetry. The tuner has a 200 kc bandwidth, flat top response, and a usable sensitivity of 2 μv. The dc voltage output of the discriminator is coupled to the input of a Dynamics dc amplifier, Model No. 6122. The two outputs of the amplifier, also dc voltages, are coupled to a 3-kc response galvanometer in a CEC recording oscillograph and to a Tektronix 545 oscilloscope (Fig. 10).

The antenna, a $\lambda/2$ loop, was placed in one window of the test section. Antenna orientation was extremely critical; however, once properly located, it was possible to have near-perfect reception throughout the test area. This was determined by mapping the antenna pattern with a telemeter. The most troublesome areas were the window edges, because the window size was very close to the $\lambda/2$ at operating frequency.

During each flight launched during this study, a Fastax camera was used to provide optical data (Ref. 2) to correlate model position with data trace.

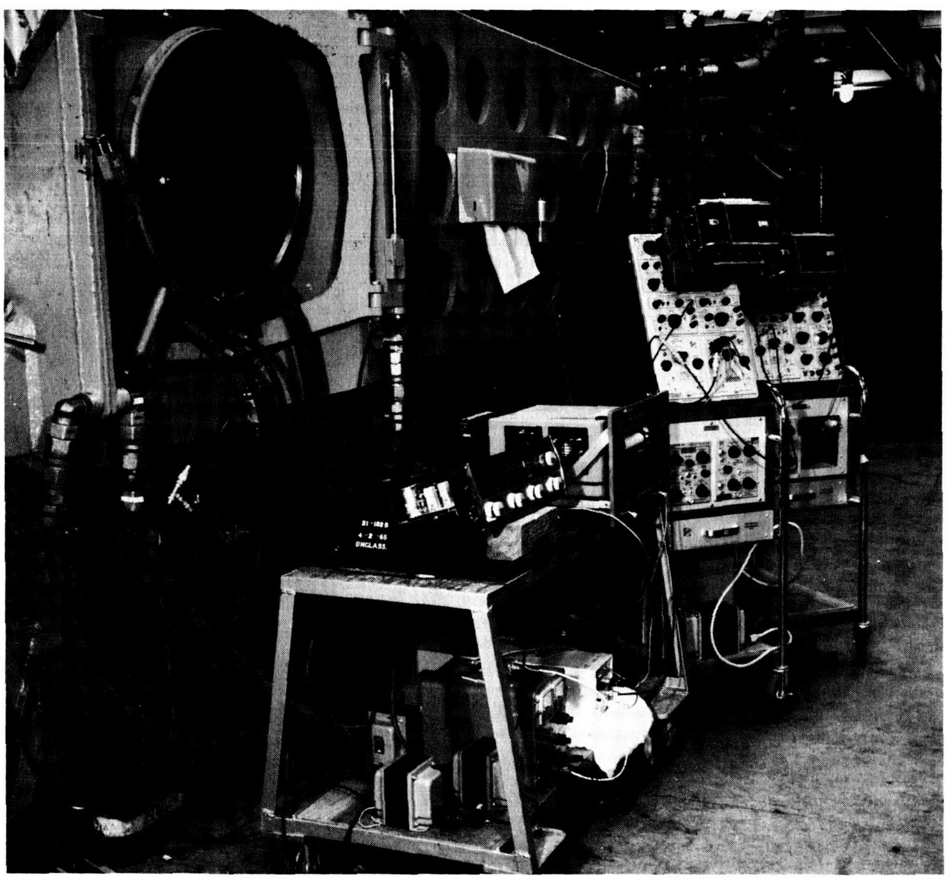

Fig. 10. Tunnel installation of instrumentation

VI. TECHNIQUE OF OPERATION AND PROBLEMS ENCOUNTERED

The JPL free-flight techniques reported here are similar, in many respects, to those that have been successfully developed at other facilities (Ref. 3). However, the pressure telemeter, itself, is different; it is a more flexible instrument than previously used. Description of launching hardware (Ref. 4), other than its relationship to the operating sequence (Fig. 11), is not described in this paper.

The subject tests comprised 134 flights, which were accomplished with 12 pressure telemeters. The experiments were conducted in the following described manner.

When the wind tunnel was ready for data recording, the tuner and scopes were zeroed and triggers set. Then, a reference base-pressure was recorded on the wind tunnel data system and, immediately, the heat shield was

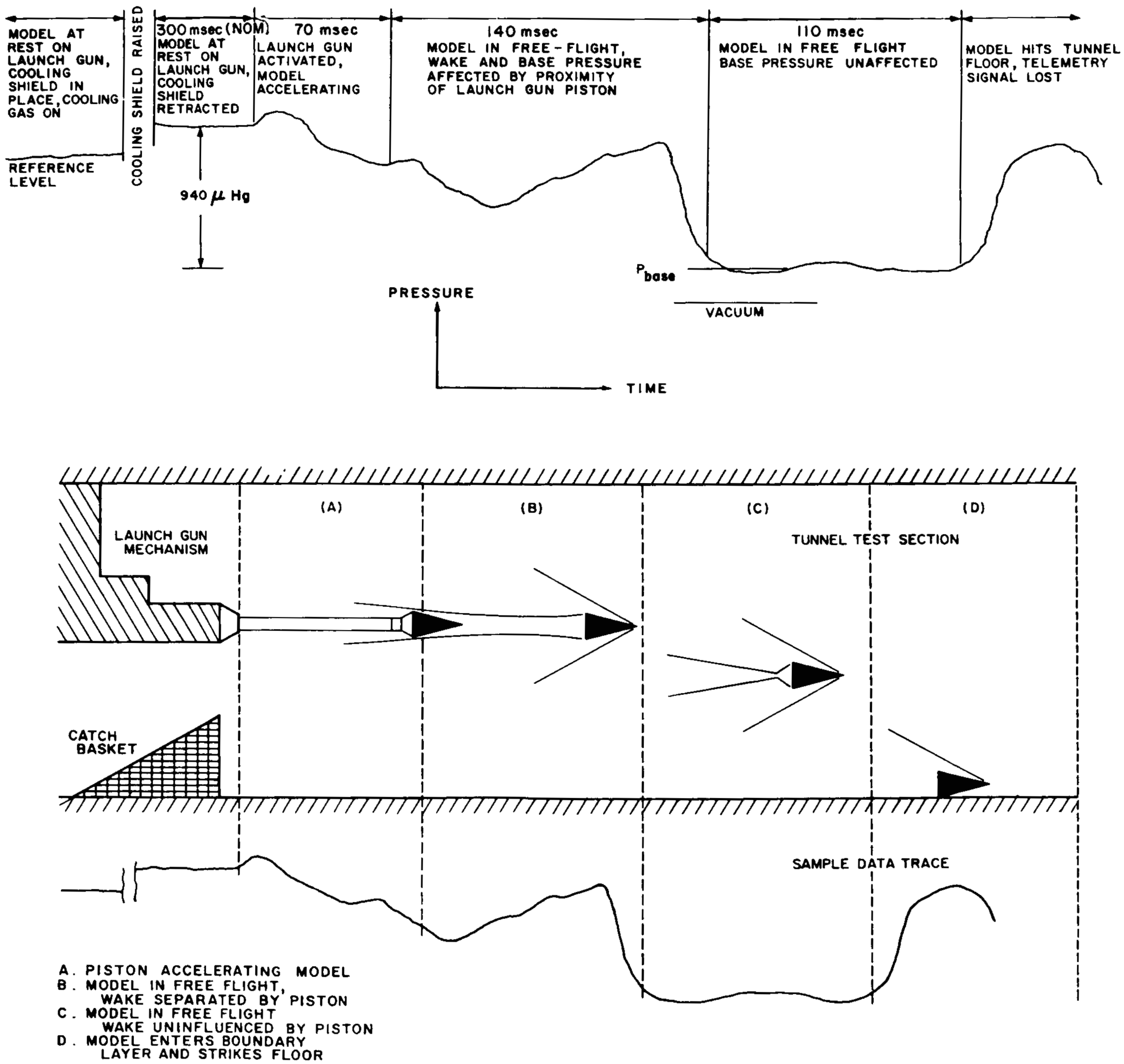

Fig. 11. Examples of timing and model position on data trace

raised. A switch closure at the top of the heat-shield travel started the Fastax camera, and an event timer on the camera started the recording oscillograph. A second event timer started the launch gun and triggered the oscilloscopes. It was found that, with few exceptions, the pressure telemeter performed properly.

For a variety of reasons, a number of runs were lost for data purposes. Improper timing and poor antenna patterns at the beginning of the test program accounted for several such instances. When these problems were solved, it was discovered that an unsatisfactory dew point was producing poor data. Other runs were lost because of (1) improper cooling and subsequent damage to the model, (2) battery failure in the telemeter, (3) shorted sensor in the telemeter, and (4) power-line loading causing a tuner shift. The majority of the data curves of the lost runs indicated that the pressure telemeter functioned properly but that the relationship to the initial reference pressure recorded was lost. The faulty antenna system, of course, did not produce a normal curve (Fig. 12).

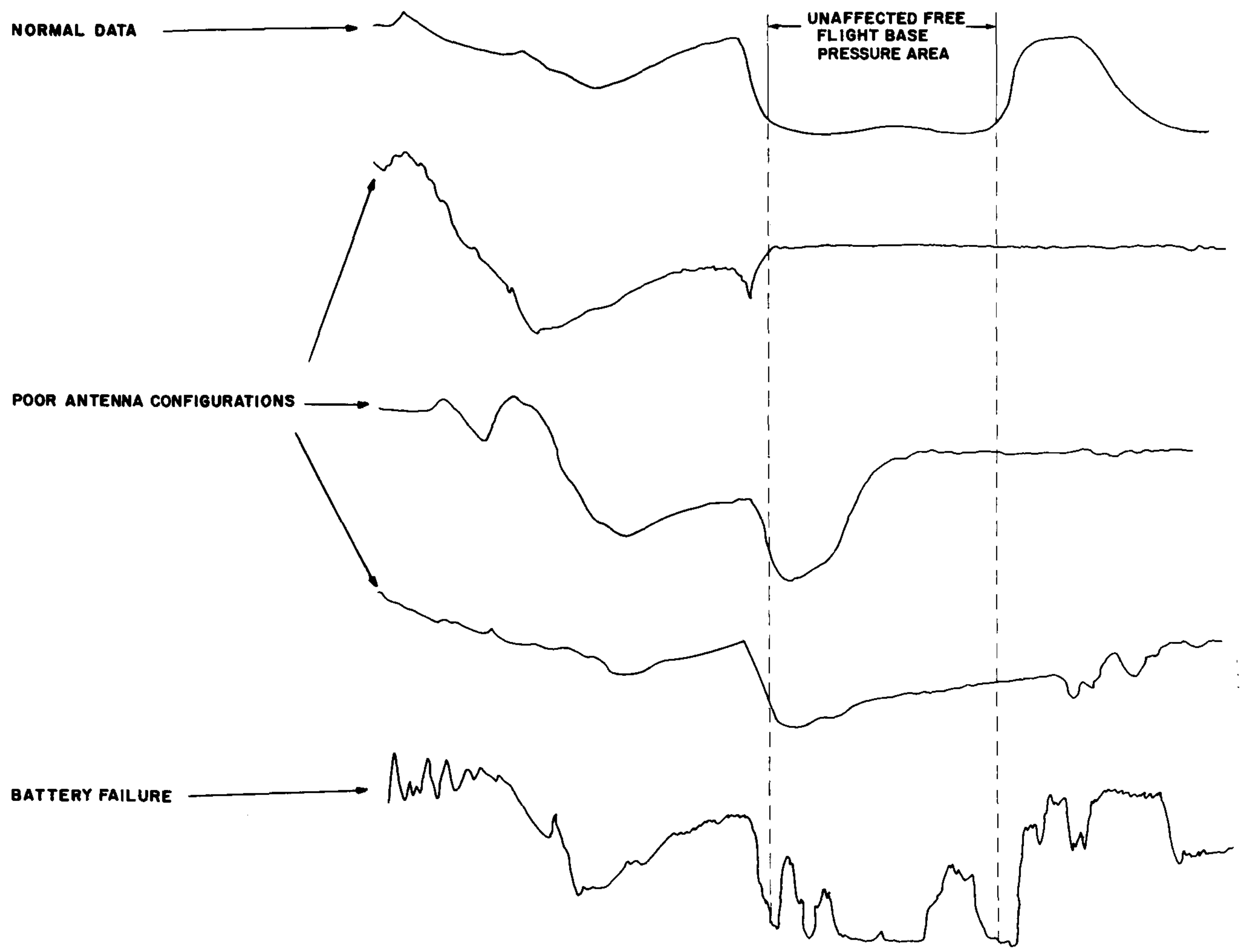

Fig. 12. Examples of good and bad data curves

VII. CONCLUSION

The data acquired in the Pressure Telemetry Development Program from tests in the hypersonic wind tunnel are summarized in Ref. 1. The close correlation between theoretically predicted and actual experimental data is shown in Fig. 13.

The pressure telemeter is considered operational and capable of producing valid data. Its use is advantageous in that neither special instrumentation nor special skills are required in its operation.

Capabilities of the telemetry system can be improved immediately by obtaining tuners with wider bandwidths than that used in the development program. In future tests, the wind-tunnel data system will be fully utilized to achieve greater accuracy; and data acquisition, in general, will be improved.

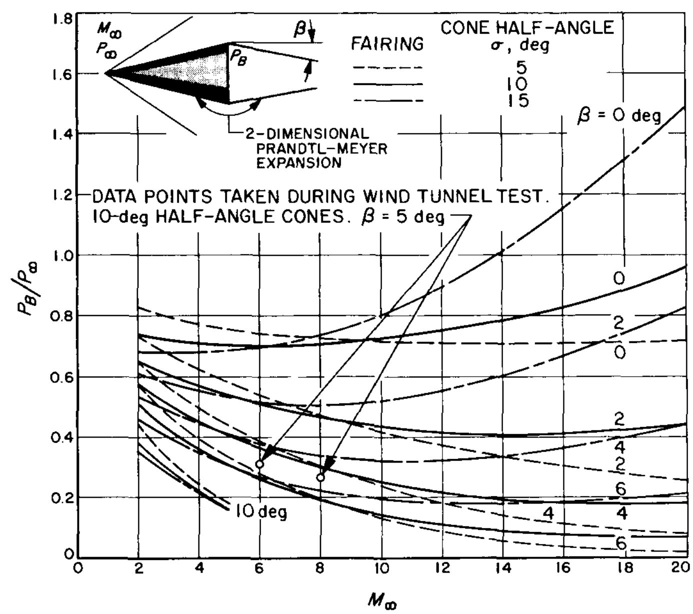

Fig. 13. Ratio of cone base pressure to free-stream static

REFERENCES

1. Welton, John T., *Free Flight Telemetry Testing in the Jet Propulsion Laboratory Wind Tunnels,* Technical Report 32-775, Jet Propulsion Laboratory, Pasadena, California, September 15, 1965.

2. Dayman, Bain, Jr., *Optical Free-Flight Wake Studies,* Technical Report No. 32-364, Jet Propulsion Laboratory, Pasadena, California, November 1, 1962.

3. McDevitt, John B., Harrison, Dean R., and Lockman, Wm. K., "Measurement of Pressures and Heat Transfer by FM Telemetry from Free-Flying Models in Hypersonic Tunnel Streams," *IEEE Proceedings of the 1st International Congress on Instrumentation on Aerospace Simulation Facilities,* N65-13938, NASA, Washington, D.C., 1964.

4. Holway, H. P., Herrera, J. G., and Dayman, B., Jr., *A Pneumatic Model Launcher for Free-Flight Testing in a Conventional Wind Tunnel,* Technical Memorandum No. 33-177, Jet Propulsion Laboratory, Pasadena, California, July 30, 1964.

ACKNOWLEDGMENTS

For their contributions to the successful development of a pressure telemeter, the author expresses his appreciation to Larry Bennett, Ray Hill, and Roy Anderberg for their patience and perseverance in the fabrication and calibration of the basic unit; to Paul Votava for his assistance in selecting the microminiature circuit package; and to John T. Welton for his careful supervision of the wind tunnel test program and the data reduction.